Utilizing Meteorological Data from Commercial Aircraft for Urban Boundary Layer and Air Quality Applications

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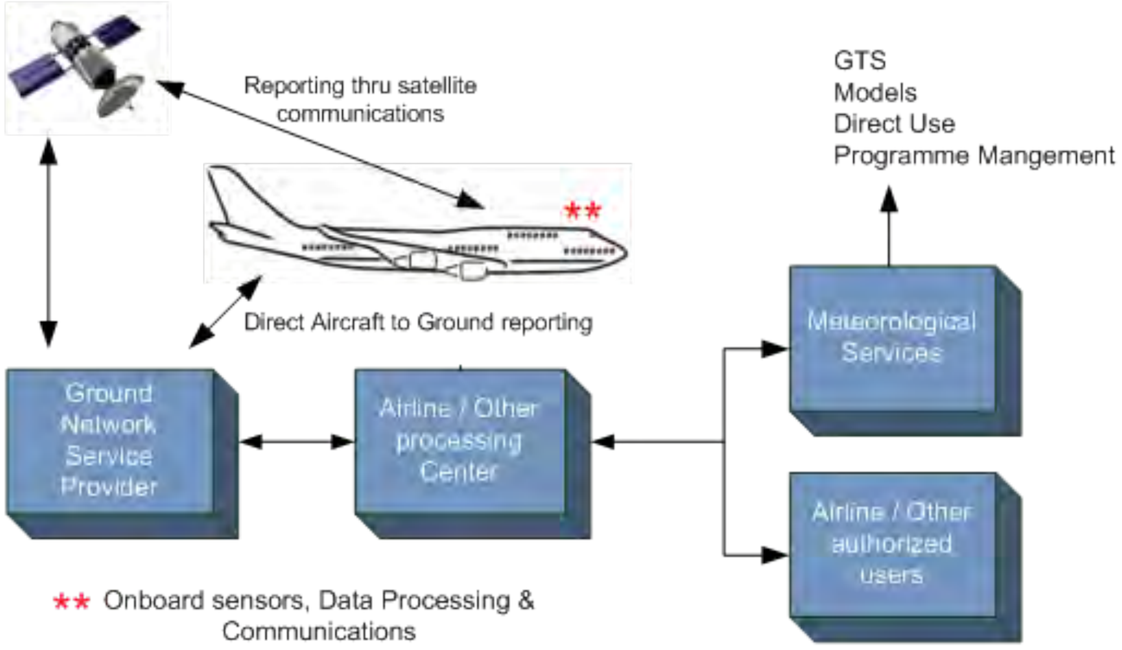
2025 AiRMAPS Workshop: Sept. 3rd-Sept. 4th

What is ACARS and How Does it Work?

- ACARS stands for Aircraft Communications Addressing and Reporting System
- Data is transmitted via satellite to a ground network and used for a variety of applications including the generation of forecast reports and data assimilation
- Can also transmit directly to the ground via VHF transmission
- Data can be made available minutes after transmission
- Archived and near realtime data is publicly available

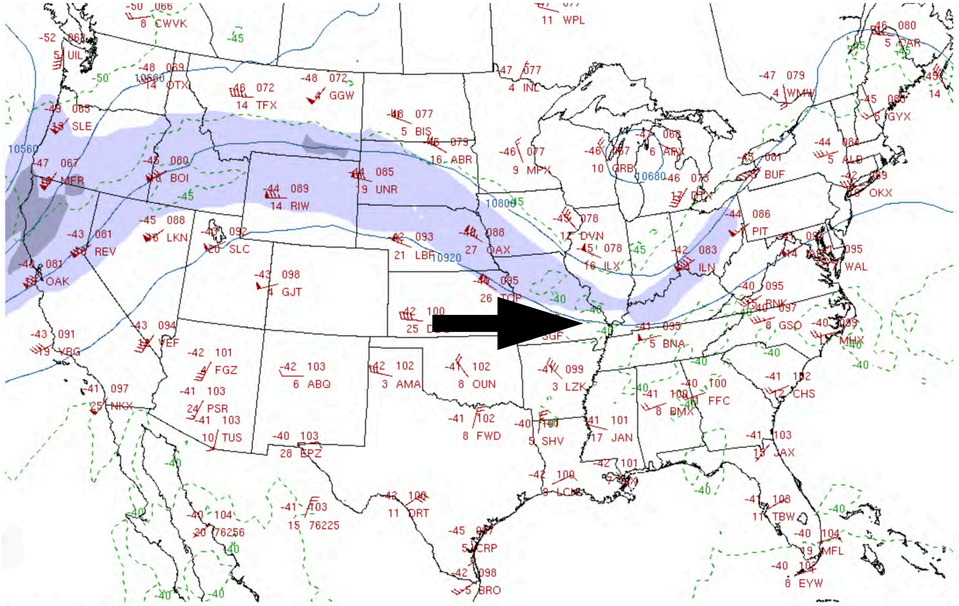


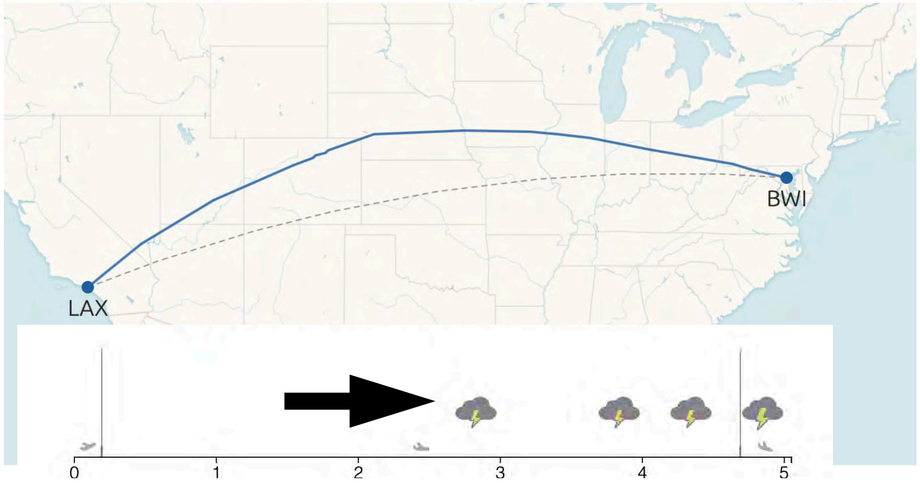
What's Reported?

- Positional data
- Wind speed and direction
- Eddy dissipation rate (EDR)
- Temperature and dew point
- Flight number
- Time
- Icing indication

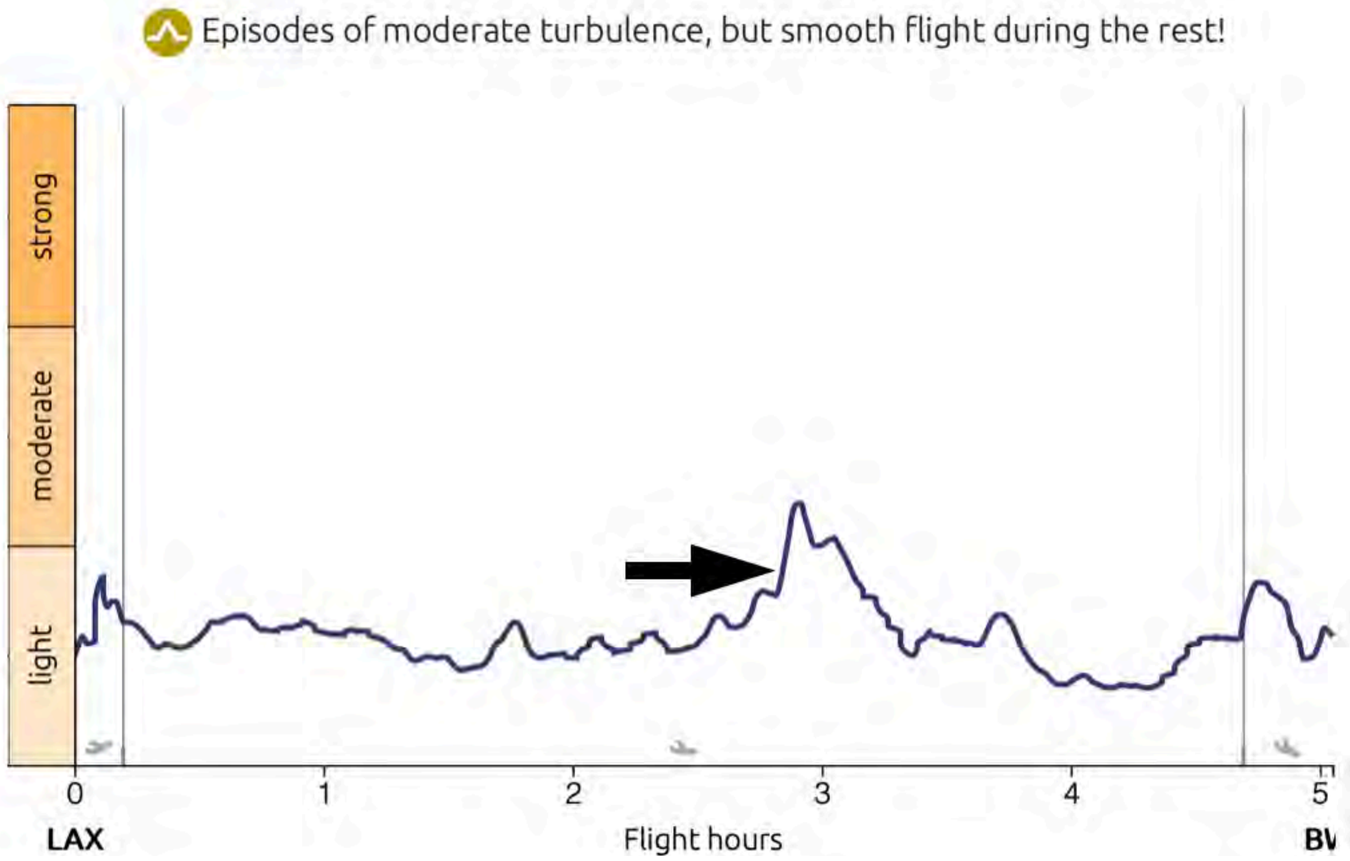
How is the ACARS Data Used?

Generate clear air turbulence (CAT) reports to inform commercial aircraft





- Increase in EDR near thunderstorm activity and jet streak (note ramp-up in tail wind)
- Smaller increases near mountain ranges



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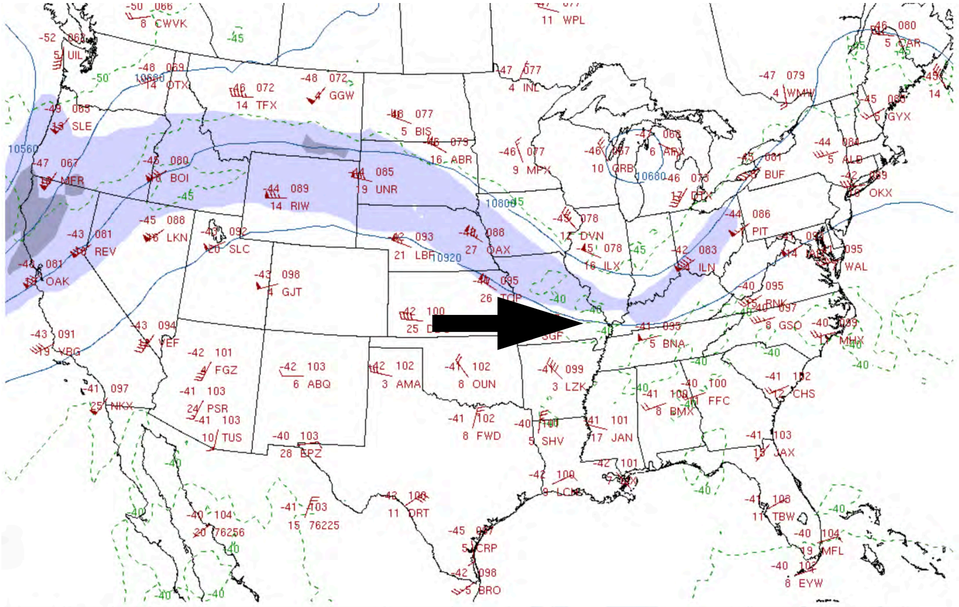

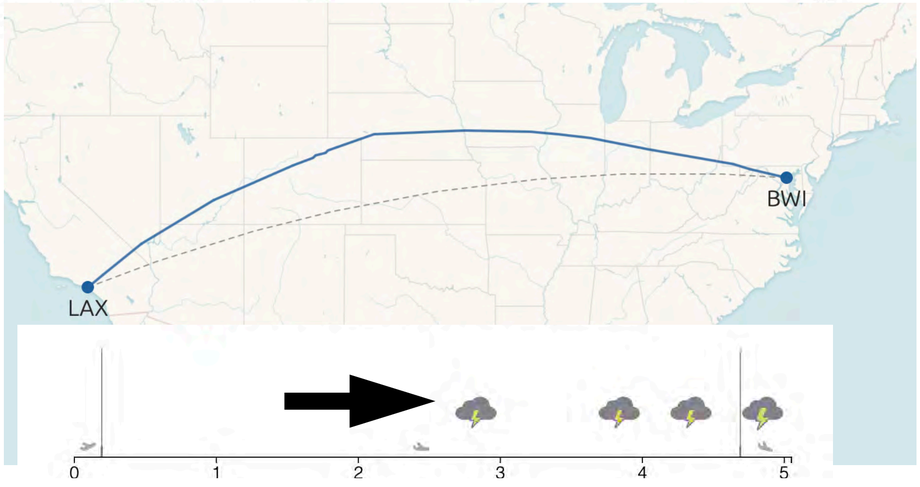

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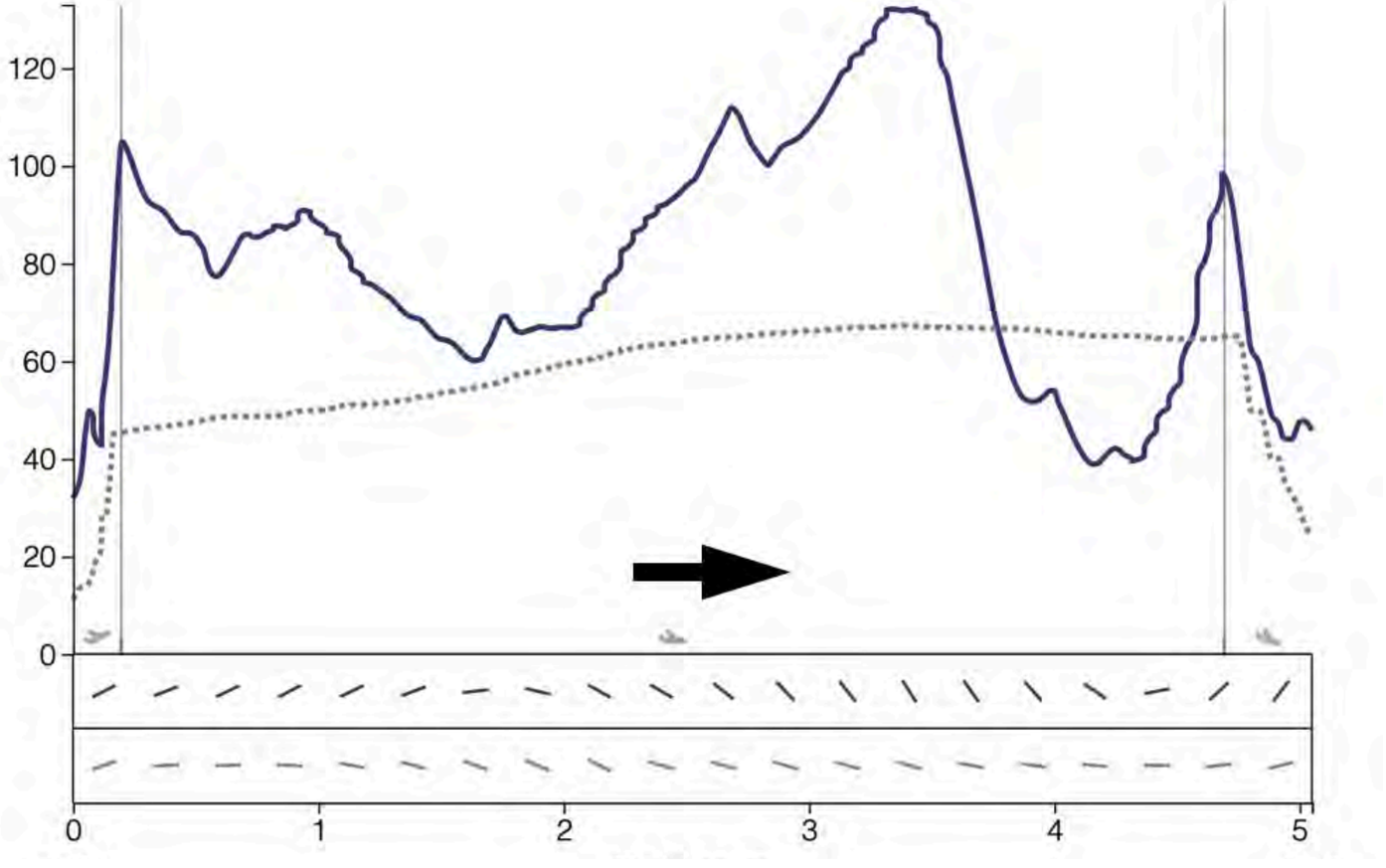
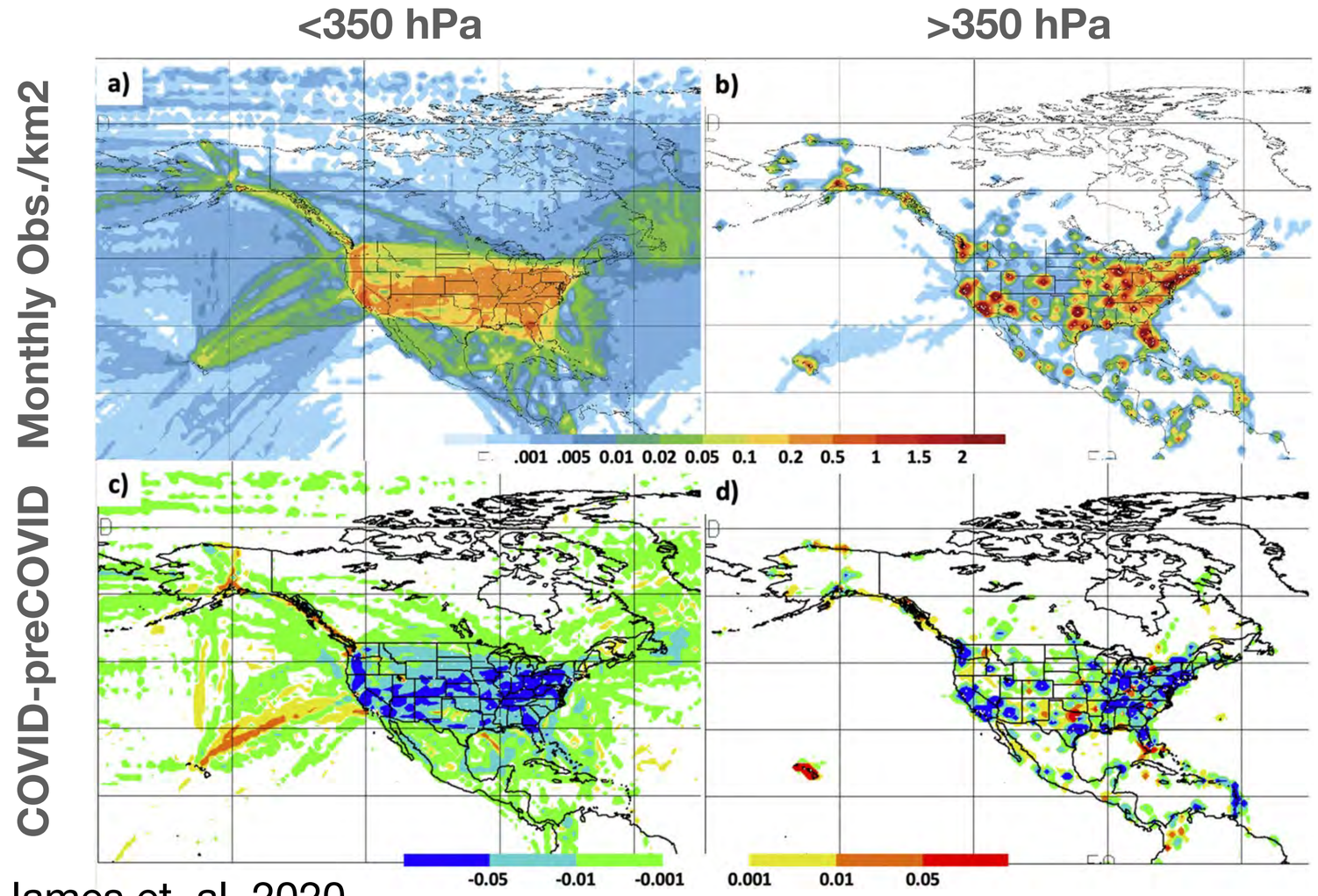


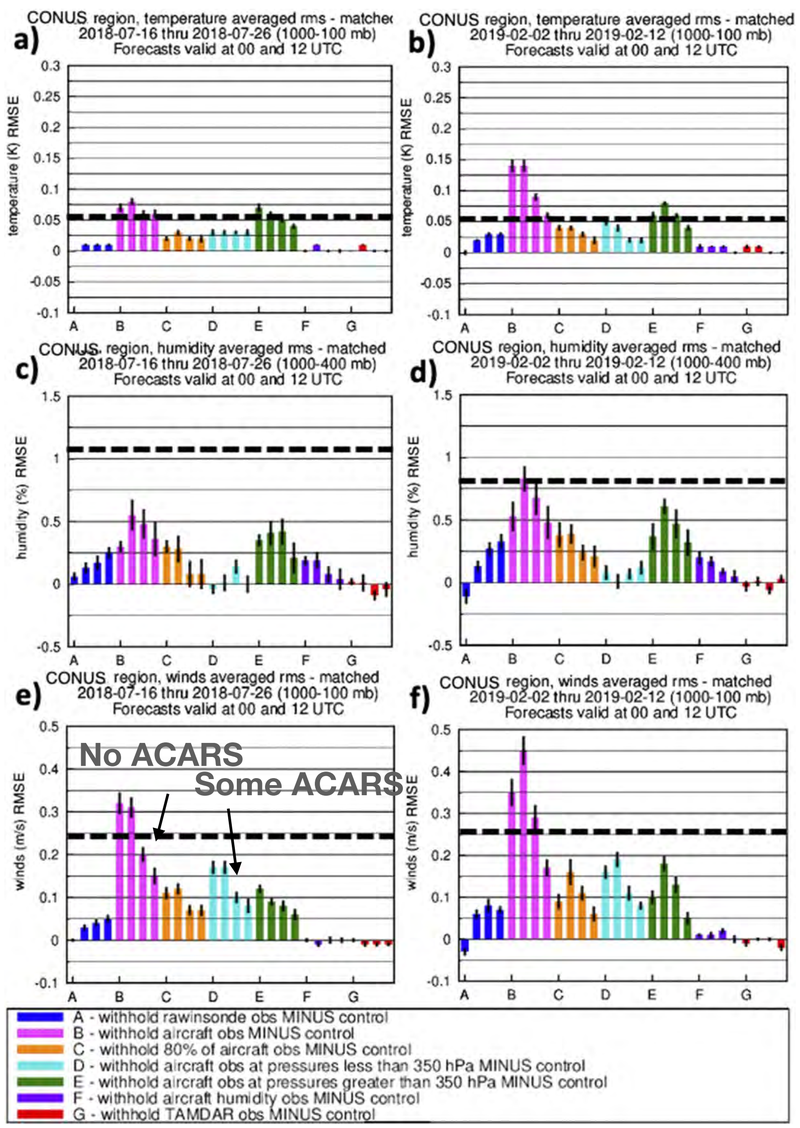
How is the ACARS Data Used?

Data Assimilation and Model Evaluation

- Assimilating aircraft observations (control) into the model improves model performance for all variables evaluated



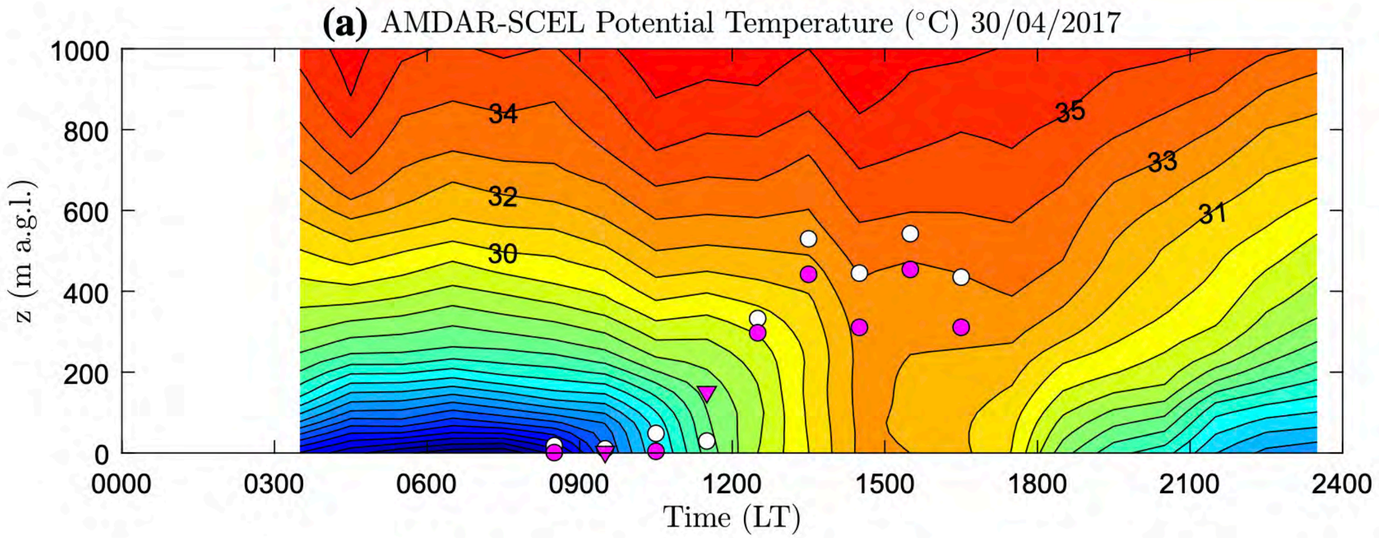
James et. al. 2020

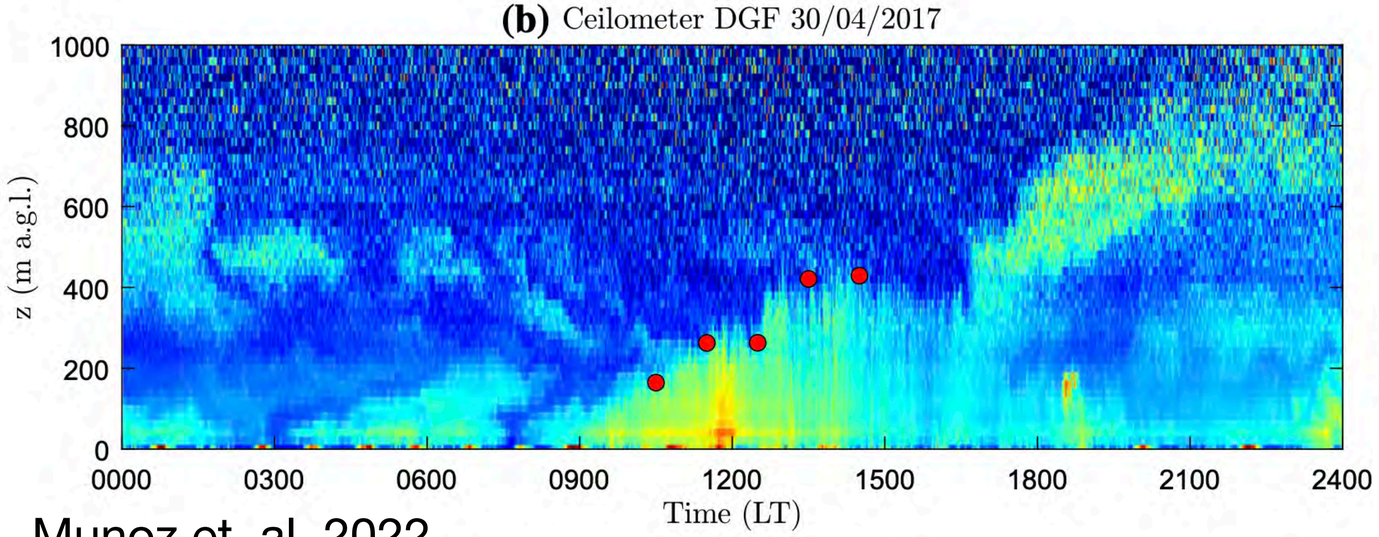


How is the ACARS Data Used?

Boundary Layer (BL) Profile and Depth Analysis/Evaluation

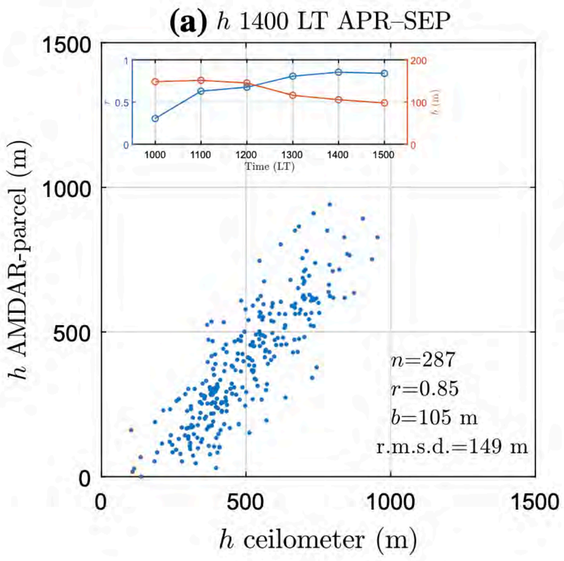
Santiago Valley, Chile

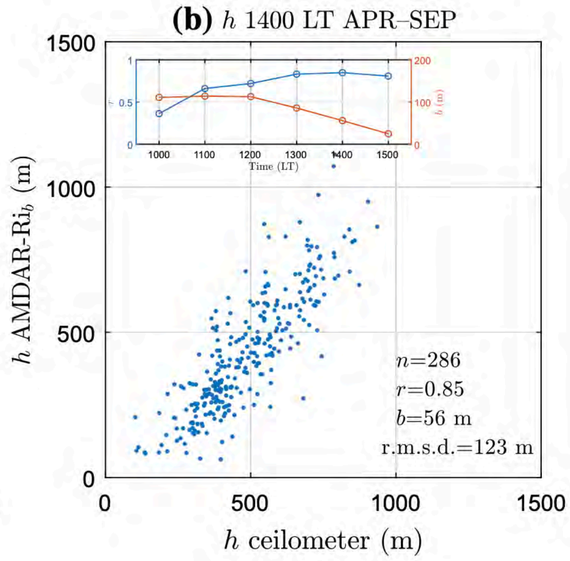




Munoz et. al. 2022

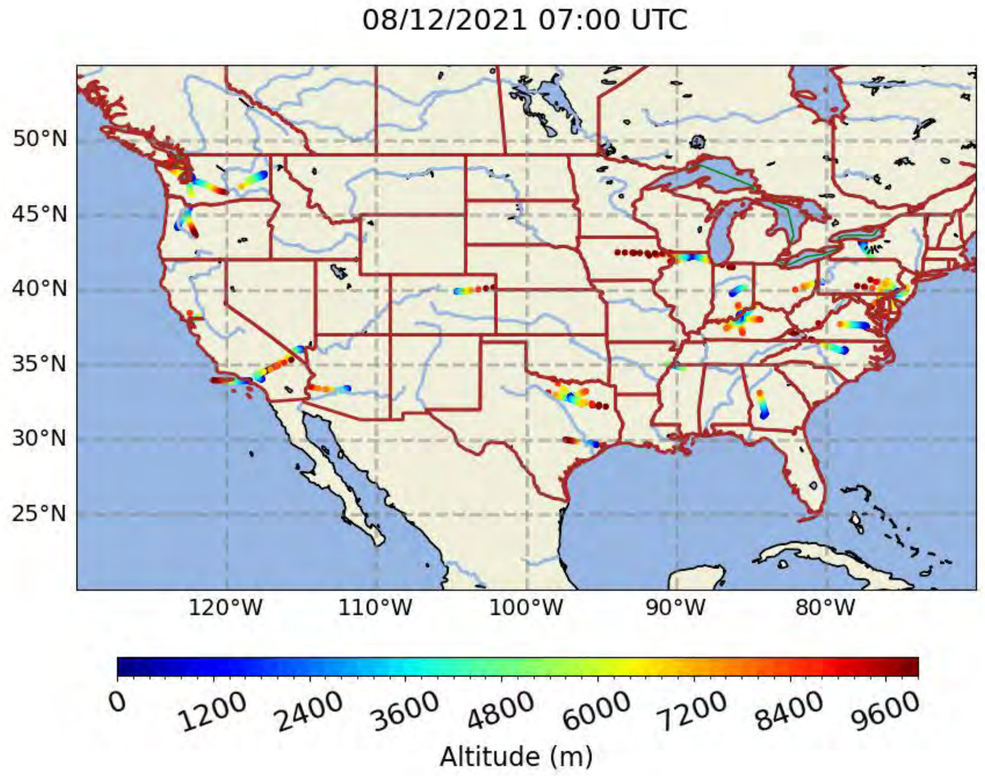
- Nearly a continuous set of profiles showing diurnal structure
- BL height derivations focused on convective BL use different methods
  - θ-method
  - Bulk Richardson Number
- Studies show good agreement with other observations

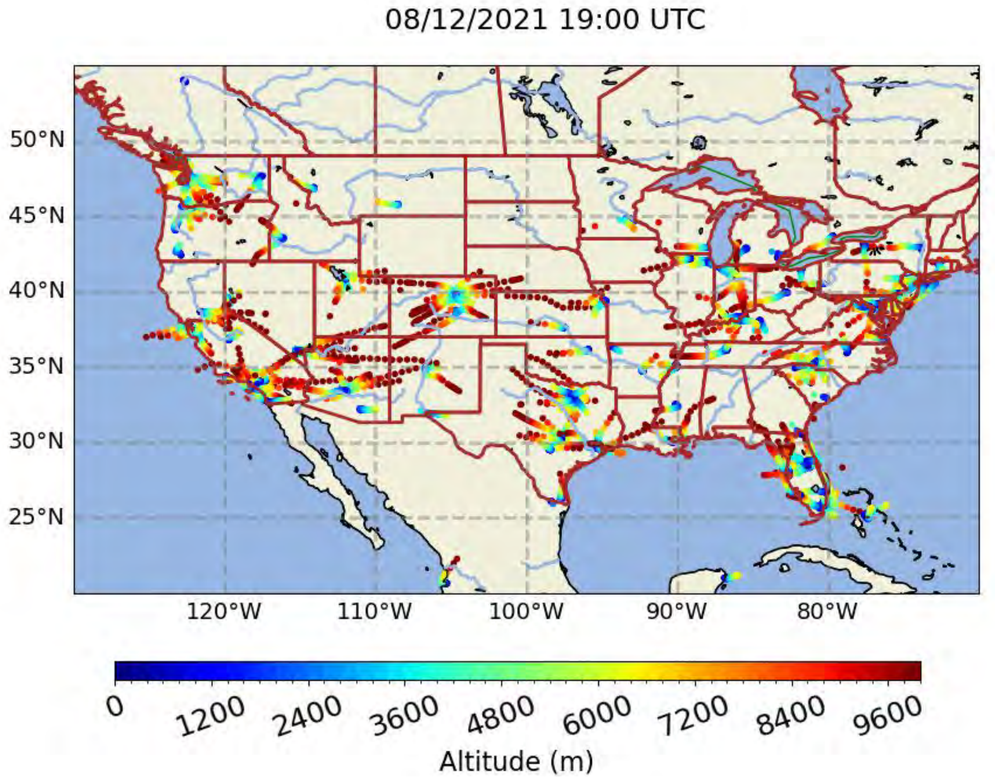




Distribution of Airports in CONUS

- Busier airports have multiple flights transmitting meteorological data during the day and maintain some data continuity throughout the night
- Data still underutilized as an evaluation tool
- Profiles intersecting the urban boundary layer (UBL) would aid in research efforts focused on urban air quality, transport modeling, and the urban heat island (UHI)
- Data is publicly available: https://madis-data.ncep.noaa.gov/madisPublic1/data/



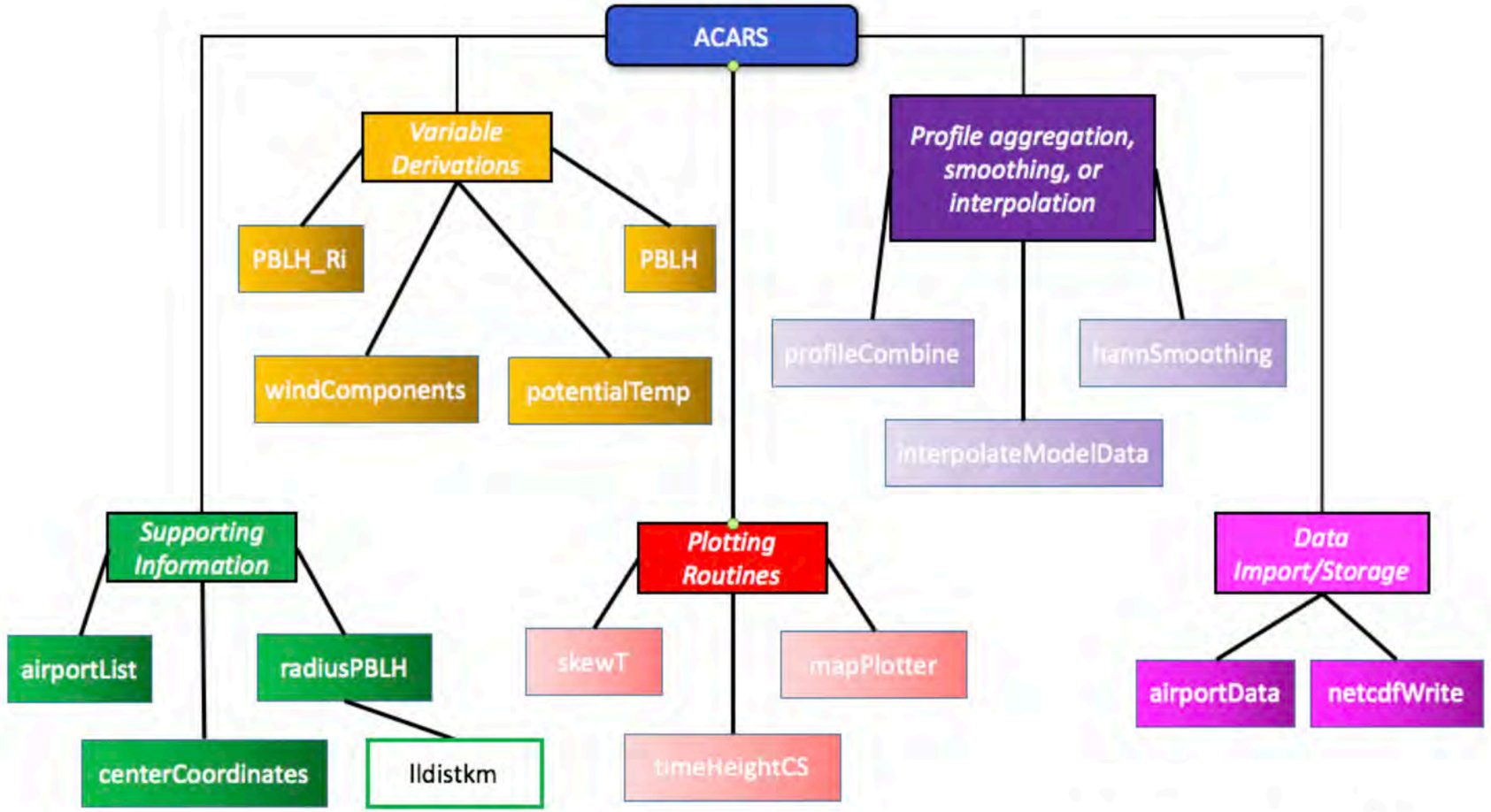


Groups Leveraging ACARS Data

Codes are being jointly developed and tested to evaluate near continuous BL profiles and depths near or in an urban environment

METplus

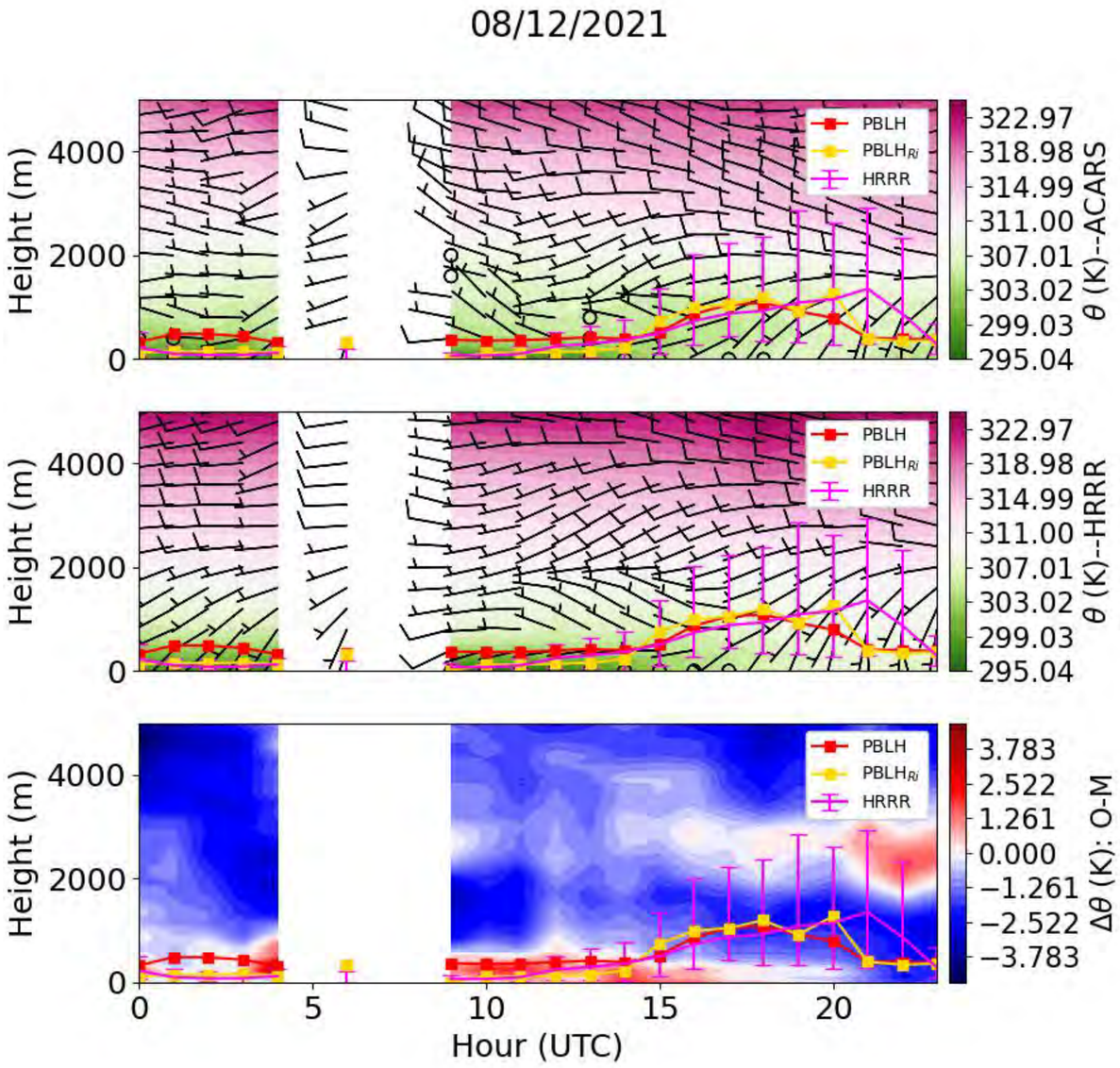
What Do We Have So Far?



- Can determine list of airports on a given day, airport location, derive BL height; aggregate, smooth, and interpolate data; plotting/visualization; and writing out netcdf files

What Do We Have So Far?

- Diurnal temperature and wind profiles with different approaches to deriving BL depth
  - Comparisons with models to understand pollution transport in an urban setting
- Descending/ascending flights into/out of an airport overlaid with flight-level winds, and profiles averaged +-30 minutes within an hour
  - Useful for providing spatial context of how meteorology is represented across a complex landscape
- Log-p/Skew-T plots with hodographs and severe weather indicators
  - Can serve as a data point for determining Severe weather in an urban environment



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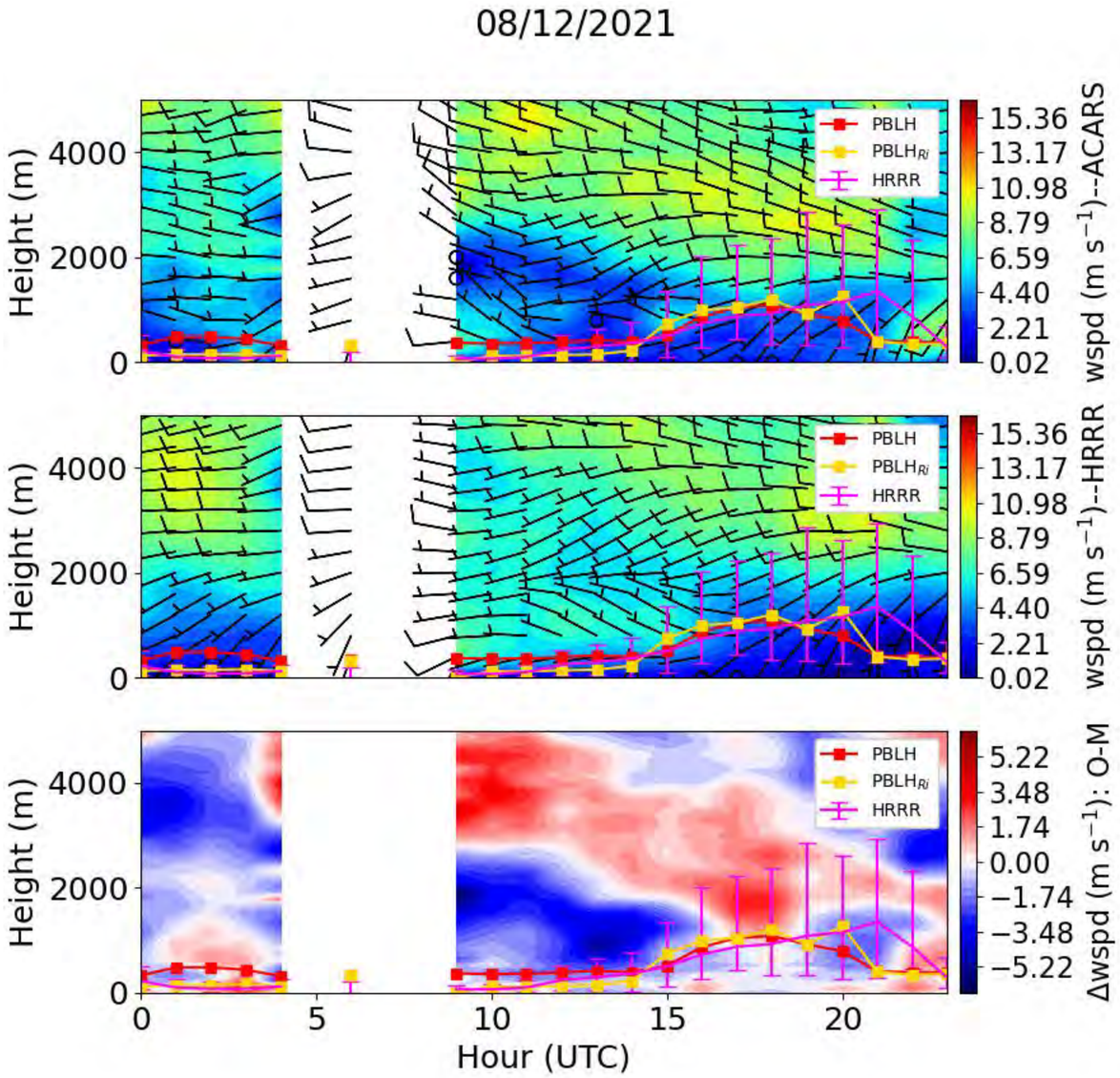

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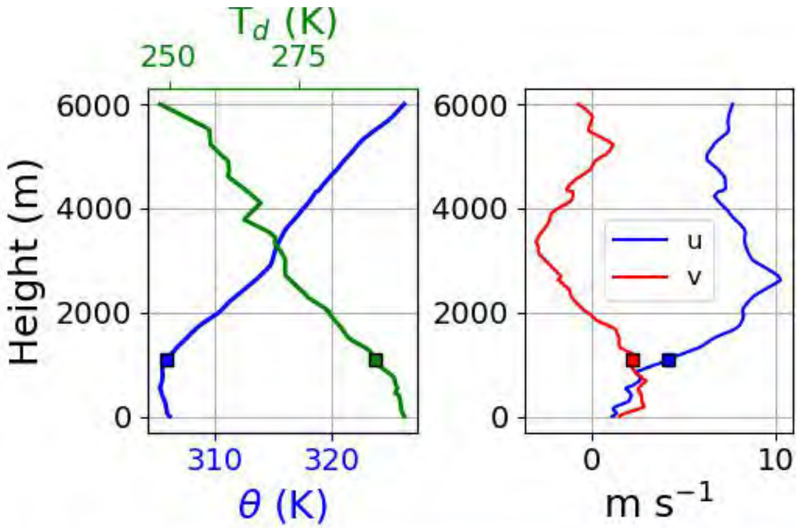

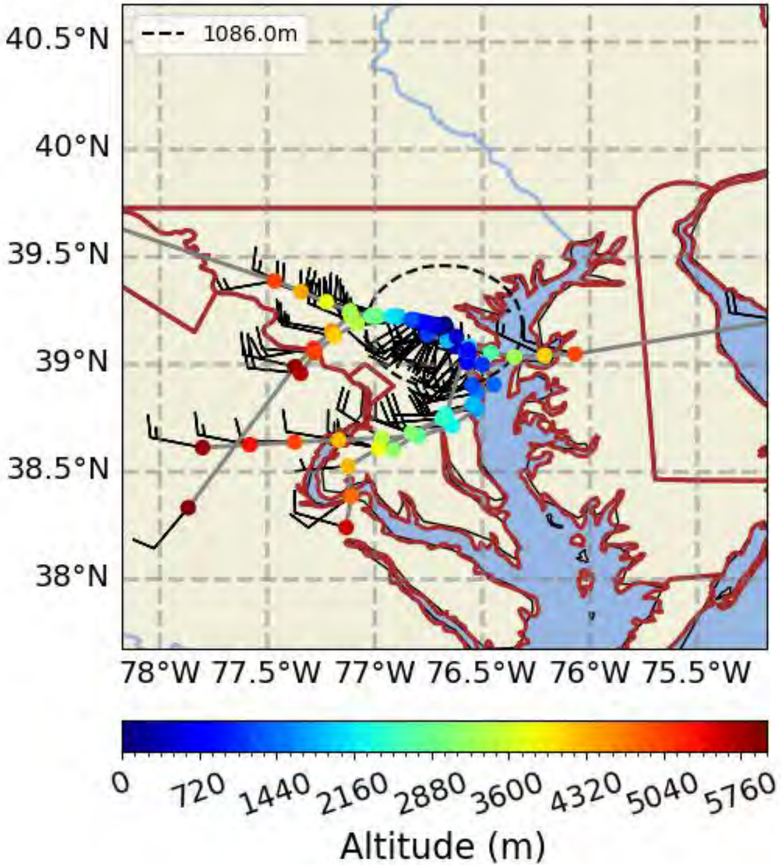

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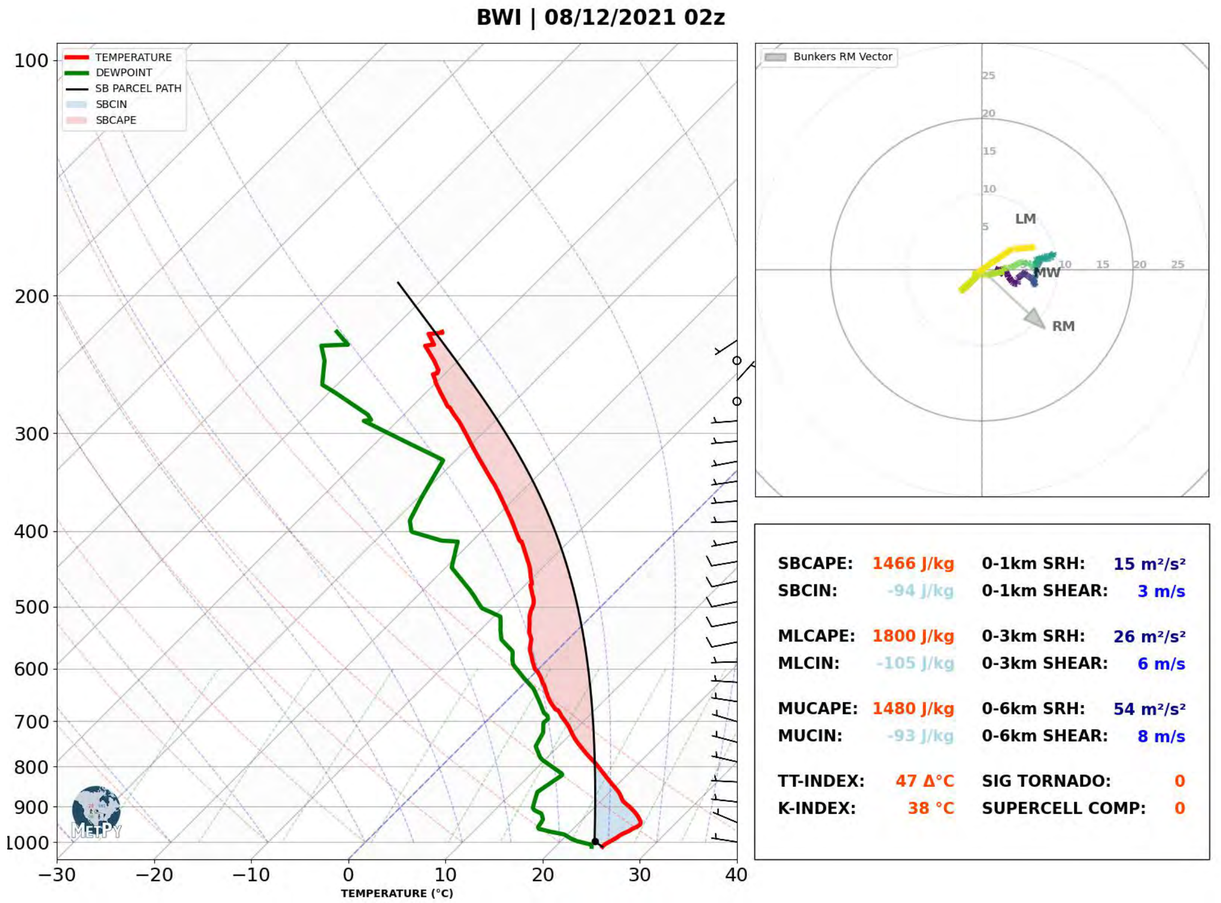
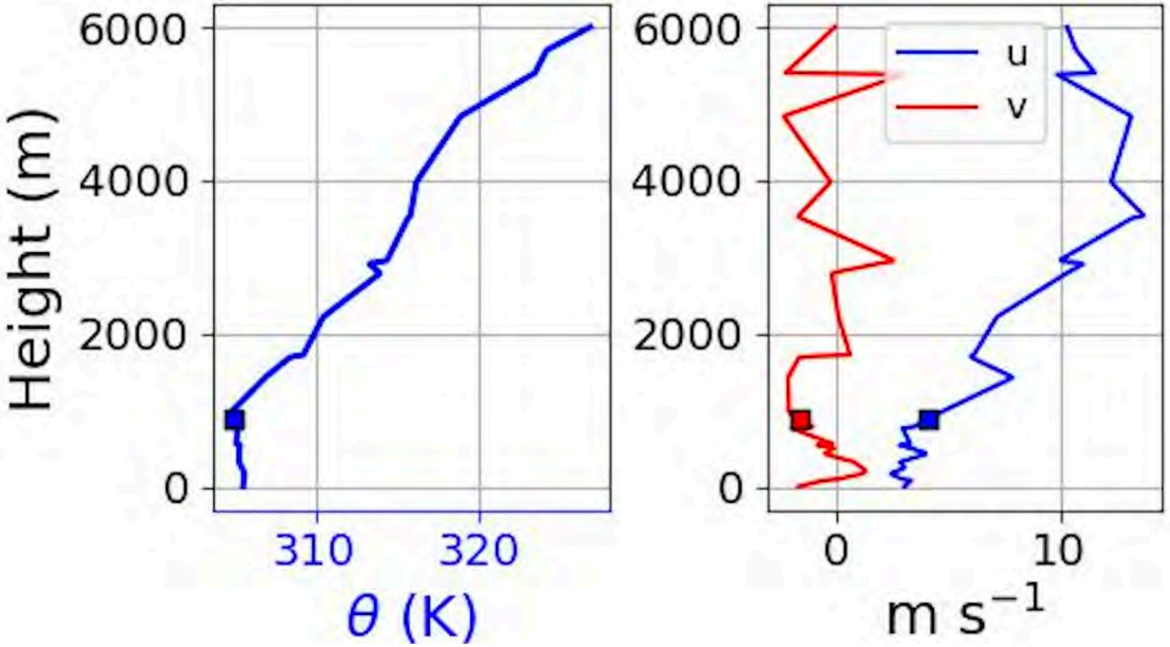
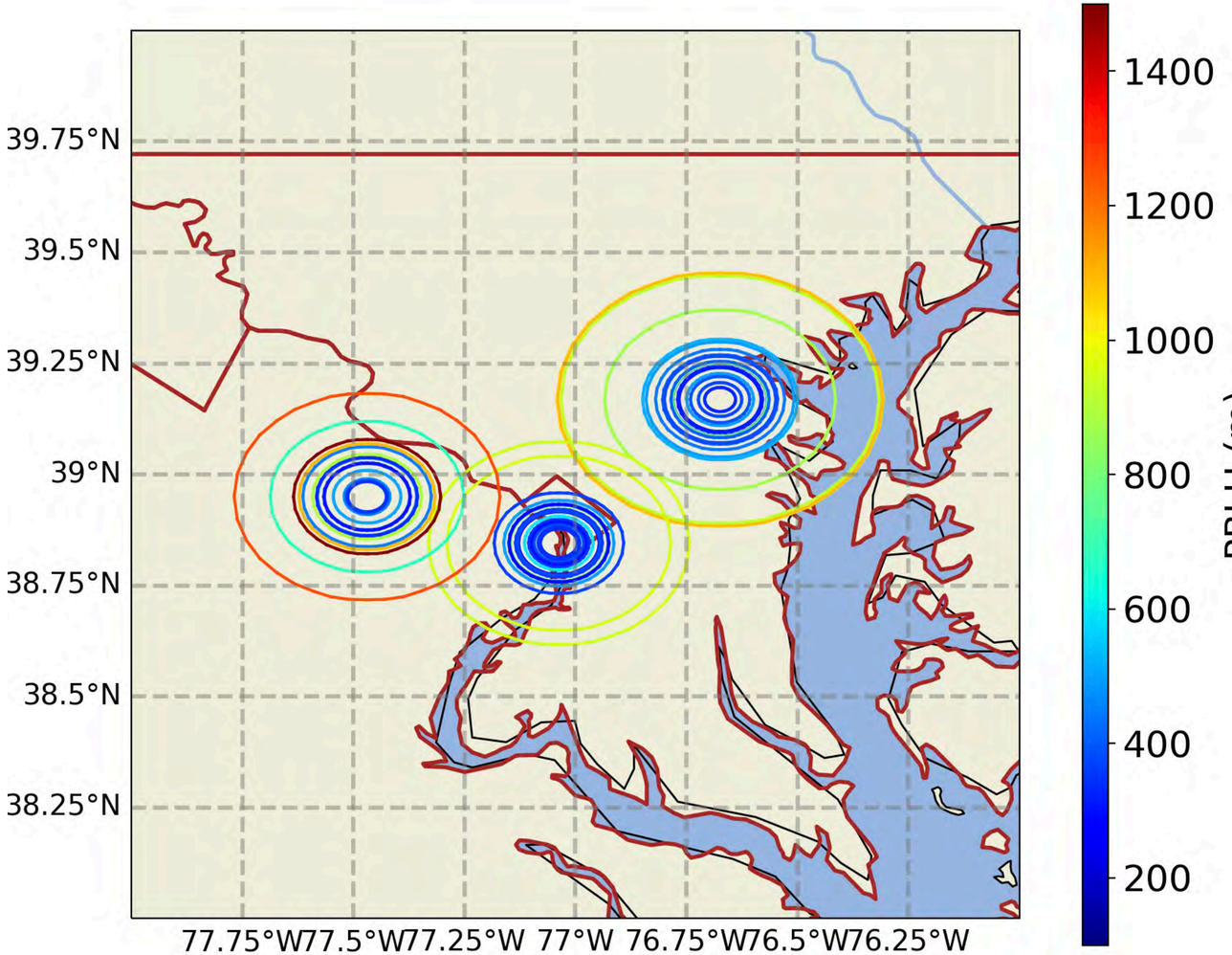


Next Steps: BLH Determination and Field Deployments

- θ-method: identifying instance in the vertical where θ equals the surface value
  - Works only for convective BL
- Bulk Richardson Method (Zhang et. al. 2014):
  - $$Ri_b = \frac{g}{\theta_{vs}} \frac{(\theta - \theta_{vs})(z - z_s)}{(u - u_s)^2 + (v - v_s)^2 + bu_*^2}$$
- Wavelet smoothing approach: under development



- **Large distances traveled by aircraft could complicate the BL detection algorithm**



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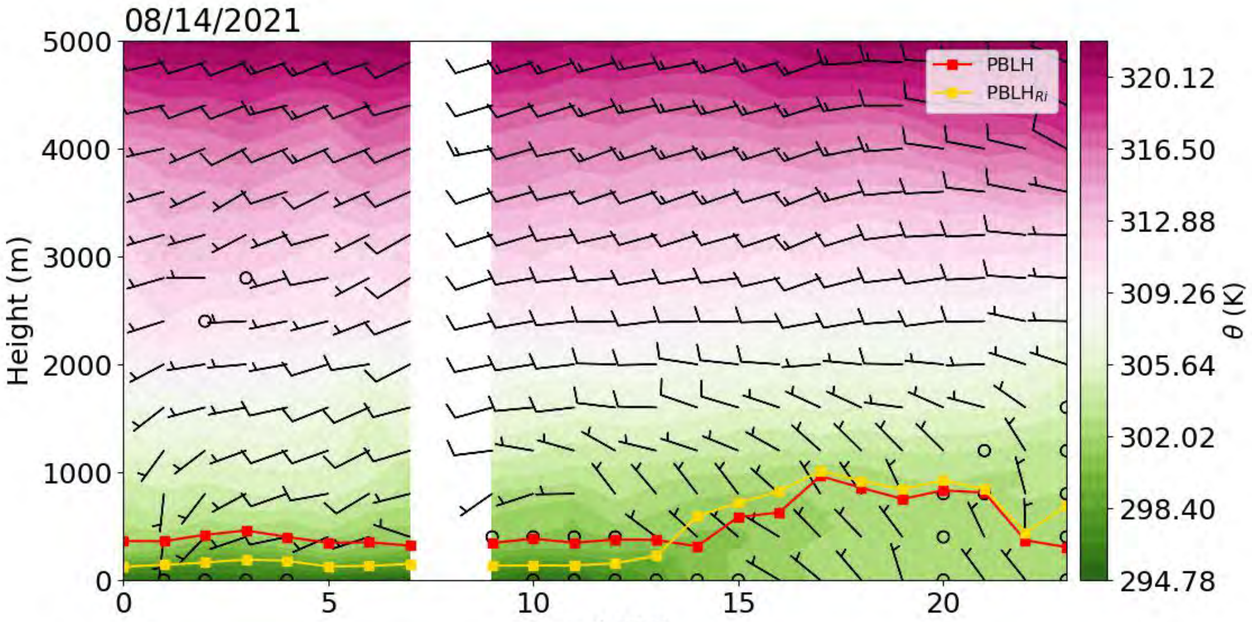
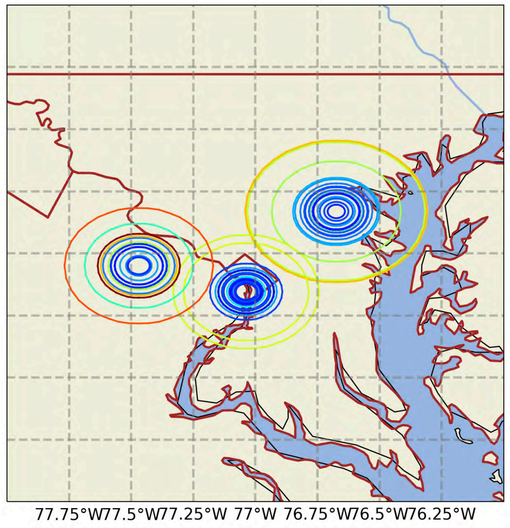
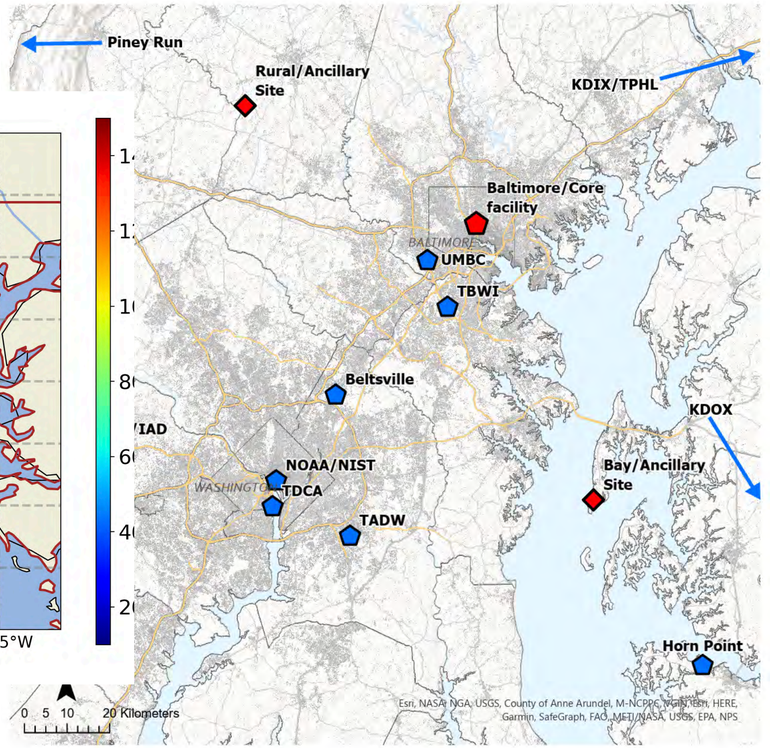


- Plans underway between CSL, GSL, and UMD to determine best algorithm Detection approach for key airports of interest, including airports in the Baltimore Washington area—just in time for the Coastal-Urban-Rural Atmospheric Gradient Experiment (CoURAGE)





Concluding Remarks

- Code has been developed to take advantage of frequent meteorological profiles derived from commercial aircraft, which offers another dataset for deriving BL heights
- A collaborative effort is underway to determine a preferred approach for deriving BL heights, which would be critical for studies focused on
  - Urban Boundary Layer
  - Transport modeling across a complex landscape
- Code is being prepped for ingesting real-time data in cities where future field deployments are planned (e.g., CoURAGE), which can be used as a supporting data set or to predict the likelihood of severe weather developing when flights are planned over cities
- Routines available to store airport specific data in real-time that can be later used for statistical analyses of the model

References

1. Zhang, Y., et al. "On the computation of planetary boundary-layer height using the bulk Richardson number method." *Geoscientific Model Development* 7.6 (2014): 2599-2611.
2. James, Eric P., Stanley G. Benjamin, and Brian D. Jamison. "Commercial-aircraft-based observations for NWP: Global coverage, data impacts, and COVID-19." *Journal of Applied Meteorology and Climatology* 59.11 (2020): 1809-1825.
3. Muñoz, Ricardo C., et al. "Using commercial aircraft meteorological data to assess the heat budget of the convective boundary layer over the Santiago Valley in Central Chile." *Boundary-Layer Meteorology* 183.2 (2022): 295-319.